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Characterization of a multi-electrode common-ducted HHO dry cell

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Abstract

Electrolytic production of hydrogen from water is gradually gaining its importance among the other conventional process of hydrogen production in the context of renewable energy source utilization and environmentally clean technology. The present work study hydrogen gas production in a form called Brown's gas or HHO gas by alkaline water electrolysis with KOH as electrolyte in an 11 plate common-ducted HHO dry cell. The variation of HHO gas flow at different concentrations of electrolyte was investigated. During electrolysis the temperature of the electrolytic solution is also found to increase gradually with time due to overvoltages, which further effects the current, electrical and gas production rate. The effects of temperature on the HHO gas production rate and energy efficiency of electrolysis process are discussed.

Key words: Alkaline water electrolysis; Brown's gas; temperature effect; HHO dry cell.

Introduction

Addition of hydrogen gas as fuel supplement in internal combustion (IC) engines has recently been attracting the interests of engineers and scientists worldwide because of its various beneficial effects.[1-3] These effects include improvement in engine torque, brake thermal efficiency, specific fuel consumption and reduction in engine emissions of unburned hydrocarbons (HCs), CO, NOx, smoke and particulate matter. In such application of hydrogen gas, among various methods available, generation of hydrogen in a form called Brown's gas by alkaline water electrolysis is considered to be a safe, convenient and low-cost method. However, producing the hydrogen on board via electrolysis requires electricity that must come from the alternator. That means an extra load on the engine, which may be tough to make up from the hydrogen. It is therefore important to have maximum electrolysis efficiency for the overall engine efficiency and fuel economy. Brown's gas is the name given to a mixture of hydrogen and oxygen in stoichiometric ratio 2:1 generated in common ducted electrolyzer unit.

The voltage needed to realize alkaline water

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electrolysis consists largely of reversible potential (= 1.2V at 25°C), overvoltage on electrodes and ohmic loss in aqueous solution.[4] In actual electrolysis, cell voltage is higher than reversible potential and the difference is converted into heat. Since the reaction is endothermic, heat thus caused is absorbed by the reaction until total cell voltage exceeds 1.48 V, called "thermoneutral voltage". This voltage is used for the standard of 100% efficiency. Thus thermoneutral voltage and internal resistance are important parameters to look on the electrolyzer unit intended to be used onboard for hydrogen generation.

Apart from efficiency, another important parameter of electrolytic system is the hydrogen production rate. A number of studies have shown that hydrocarbon combustion processes in IC engines requires only specific ranges of HHO gas amount depending on the engine type, fuel and operational conditions.[1,3] Adding too much amount of hydrogen gas could have negative impact on the emission, engine life and performance.[2] Thus for a given electrolyzer a compromise has to be made between hydrogen production rate and electric energy consumed by electrolysis process to minimize the loading effect on engine. As the rate of water electrolysis is affected by a number of factors such as electrolyte concentration, temperature, current density and voltage, it is therefore paramount important to understanding the operational characteristics of the electrolytic system.

In the present work we investigate the interdependence of HHO flow rate, electrolyte concentration, temperature and electrical parameters in alkaline water electrolysis with KOH as electrolyte. The electrolyzer unit selected for this study is the 11 plates 3.5" x 3.5" dry cell type, which is the most common type of Brown's gas generator designed for mobile application in light vehicles.

Materials and Methods

The electrolyzer design was based on common-ducted dry cell concept. There are 11 plates made of 316L stainless steel and arranged in series having a total of 10 separate cell chambers. Electrically, the electrolyzer is a series-parallel combination of electrodes in the form -nnnn+nnnn-, where '+', '-'and 'n' indicate the positive, negative and neutral plates respectively (Fig. 1). Three holes in vertical direction are provided in each plate for better circulation of the solution and gas. The three holes also help in stability of the current. The electrodes are separated from the others by a distance of 1.5 mm using 7 cm diameter O ring. These electrodes are finally enclosed between two Acrylic end caps attached with two hose barbs for inlet of solution and outlet of gas.

The experimental set up used in this study is shown in Figure 2. The electrolytic solutions are prepared by dissolving KOH in distilled water in the concentration range 0.5 to 2 M. Power supply for electrolysis is obtained from a 144 Ah 12V lead accumulator, which is charged to its full capacity before each experiment. The HHO gas production rate was measured by displacement of water under atmospheric pressure. Temperature of the solution during electrolysis was measured using alcohol thermometer. The current and voltage were measured with a digital multimeter. Each observation was repeated at least 3 times and the uncertainties in measurements are 1°C in temperature and 10% in gas flow rate.

Results and Discussion

Figure 2 shows the relation between HHO gas flow rate and KOH concentration at 40ºC. The gas flow rate increases gradually when the electrolyte concentration is increased from 0.5 to 2M. Similar trend was also reported by Yuvaraj *et al.* using graphite electrodes.[5] This can be explained according to the dependence of conductivity on electrolyte concentration. When more electrolyte is add the concentration of ions also increase causing more current to flow through the solution. However, due to association of ions at higher concentration the conductivity of the solution will decrease again. The conductiv-

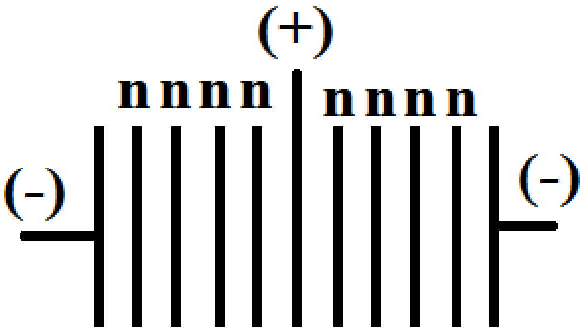

Figure 1. Structure of HHO dry cell.

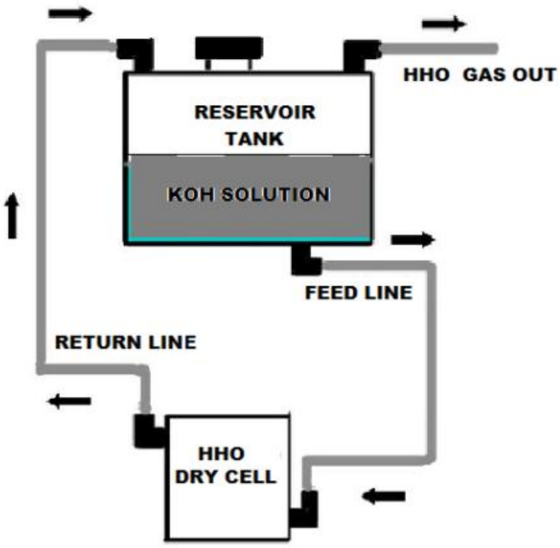

Figure 2. Experimental setup.

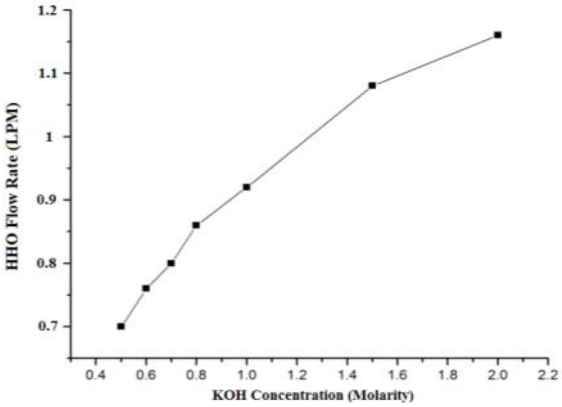

Figure 3. Variation of HHO gas flow rate (liter per minute) with KOH concentration (M) at 40°C.

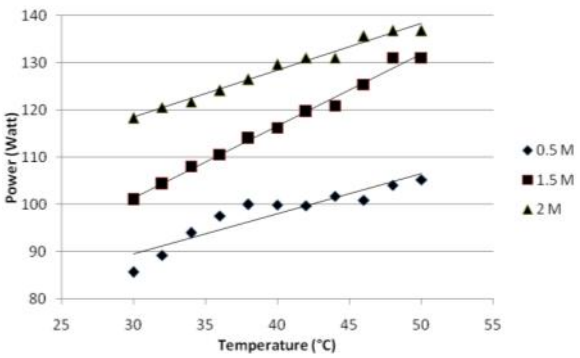

Figure 4. Effect of temperature on electrical power consumed (Watt) at KOH concentrations 0.5, 1.5 and 2 M.

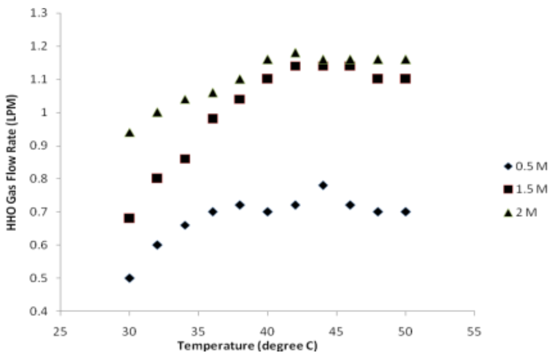

Figure 5. HHO gas flow rate (liter per minute) vs Temperature (°C) at different KOH concentrations 0.5, 1.5 and 2M

ity is reported to have maximum point at around 6.5 M.[6] The 6.5 M concentration corresponds to 26% (wt/wt), which is the concentration used for most industrial alkaline water electrolysis at current density.

The average voltage of the cell during electrolysis at 2M KOH concentration is 2.34 V which is above the thermoneutral voltage of 1.48 V for alkaline water electrolysis. As all electricity supplied beyond this point will convert into heat,[6] the temperature of the solutions are found to increase gradually with time during electrolysis. The rise in temperature is faster as the concentration of KOH increases. As the temperature increase current also increases while the voltage almost remains constant [not shown]. Figure 3 shows the plot of input electrical power vs. temperature at electrolyte concentrations of 0.5, 1.5 and 2 M. The linear dependence of power on temperature is in good agreement with the variation of conductance with temperature, which is also linear as reported by Gilliam *et al.*[7]

The effect of temperature on the HHO gas production rate at KOH concentrations of 0.5, 1.5 and 2M is shown in Figure 4. The gas flow rate first increases linearly and then tends to remain constant above 44°C. This result implies that while the current and power increases steadily with temperature (Fig.3), the hydrogen production rate appears to exhibit a point beyond which it is no longer proportional to power consumed or temperature. This observation is in contrast with the other reports that the power efficiency of electrolysis increases with temperature.[6,8] LeRoy *et al.*, pointed out that as the current density increases, the volume fraction of hydrogen or oxygen bubbles between electrodes called void fraction also increases which in turn increases the electric resistance of the cell causing the efficiency of electrolysis to decrease.[9] However, as the temperature changes from 30 to 50°C, the total internal resistance of the electrolyzer unit is found to decrease from 1.37Ω to 1.08 Ω. Thus, the apparent saturation of gas flow rate above 44°C cannot be attributed to increase in gas bubble layers or void fraction volume.

In this particular design of electrolyzer called HHO dry cell, the KOH solution is stored in a separate reservoir tank from which the electrolyte solution is supplied to the electrolyzer by gravity through the feed line. The gas output is fed back to the reservoir tank through a return line from which it is finally supplied to the point of application. The return line is always occupied by column of the solution creating pressure on the electrolysis process together with the gas inside the tank. Moreover, in most other water electrolysis studies the cell spacing used are above 2 mm;[10-12] while in our case it is 1.5 mm. The small cell spacing together with pressure are likely to favor recombination of the product H· and O· radicals back into water molecule. As the rate of hydrogen and oxygen formation increases with temperature, the regeneration of water also increases competing more and more strongly with the formation of molecular hydrogen and oxygen. When the forward product formation and back recombination are finally in equilibrium, the overall gas flow reaches a steady state as represented by saturation region in Fig.4 above 44°C.

The maximum HHO flow rate reach in this study is 1.2 ± %10 LPM at 2M concentration of KOH at 44°C. The electrical power consumed is 131 Watt. From the information seen in many open sources over the internet, one popular standard used to adjust the amount HHO enrichment level is 1/4 LPM for every 1 Liter of engine size. Therefore according to this standard, 1.2 LPM is good enough for 769 cc engine and below.

In water electrolysis, the current or Faraday efficiency is assumed to be very high reaching almost 100%.[6] Therefore the energy efficiency of the alkaline water electrolysis can be approximated by the relation

$$\text{Efficiency} = \text{Thermoneutral Voltage/ Cell voltage}$$
$$= 1.48/\text{cell voltage}$$

Using this approximation the energy efficiency of our electrolytic system is calculated to be 60% at 2.34 V cell voltage and 131 Watt. Our direct measurement has shown that the voltage available at accumulator terminals of a four-wheeled light vehicle is about 14.8 V while the engine is running. This voltage corresponds to a applied cell voltage twice the thermoneutral voltage. Therefore if the HHO dry cell is directly integrated with the engine without a current controller, the energy efficiency will be further reduced to 50% and more energy will be lost in the form of heat.

The dependence of HHO gas production rate on KOH concentration, temperature, current was studied with 11 plates HHO dry cell in alkaline water electroysis. The maximum HHO gas flow rate attained with the electrolyzer is 1.2 LPM at 2M KOH concentration and 131 watt, which corresponds to an energy efficiency of 62%. As the cell voltage used in this experiment is larger than the thermoneutral voltage, the temperature of the solution also increases during electrolysis process which further affects the hydrogen production rate. Our results showed the existence of optimum temperature range beyond which the power efficiency decreases again due to continuous loss of input electrical energy in the form of heat. The existence of optimum temperature range can be associated with the effects of electrode spacing and pressure on electrolysis process.

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